

HYDROLOGY

Precipitation

Average annual precipitation ranges between 35 and 37 inches (Klein and Daley 1974, MDNR 1986).

USGS Gaging Stations

There are eleven active gaging stations in streams of the basin (USGS 2001). Water quality was monitored at the Salt River at New London station from 1967 through 1986 and suspended sediment data was collected at the Middle Fork-Paris station from 1980 through 1997. A stage recorder is located in Mark Twain Lake.

Permanence of Flow and Average Annual Discharge

Average annual discharge at the eleven stations ranges between 67 cfs (Crooked Creek) and 2,038 cfs (Salt River). With exception of the lower Salt River, all streams are subject to periods of very low or no discharge. Only the lower Salt River is denoted by a solid blue line along its entire length on USGS maps. Nine other streams are denoted by solid blue lines for over 90% of their length (North Fork, Otter Creek, Bear Creek, Middle Fork, Elk Fork, Flat Creek, Mud Creek, South Fork, and Peno Creek). Many third-order streams are denoted as intermittent along their entire length.

Base flow and Low-Flow Frequency Data

Base flows throughout the basin are not sustained by groundwater inflow during dry weather due to the low conductivity of the underlying clays and rock. Prior to 1976, streams at all gauge sites, except the lower Salt River, were subject to seven day periods of flow less than 0.5 cfs about every five years (Skelton 1976). With the same exception, stream discharge fell below 2.5 cfs for 30 days or longer every five years. Five year recurrence intervals for the lower Salt River indicate that flow can fall to less than 12 cfs for seven days or longer and less than 37 cfs for 30 days or longer. From 1987 through 1996, instantaneous low flows ranged from 20 to 59 cfs.

Flow Duration

Flow duration statistics reflect the stream discharge that is exceeded for a specified proportion of time. Median discharge (flow exceeded 50% of the time) for the lower Salt River exceeds 400 cfs. Median discharge for North Fork, Middle Fork, and South Fork is 31, 31, and 16 cfs, respectively. The ratio of flow that is exceeded 90% of the time to flow exceeded 10% of the time (90:10 ratio) is indicative of the flashiness or variability of stream flow. The 90:10 ratios for gage stations in the Salt River basin range from 1:117 for the Salt River at New London site to 1:4,400 for Lick Creek at Perry. These ratios indicate that stream flows are highly variable. Small precipitation event cause rapid increases in stream flow because most water runs off quickly due to the low permeability of the underlying strata.

Flood Frequency

Alexander and Wilson (1995) determined through multiple regression techniques that drainage area and main-channel slope can be used to estimate return period flows for unregulated streams in Missouri. The generalized least squares regression equations are as follows:

$$\begin{aligned}Q_2 &= 69.4A^{0.703}S^{0.373} \\Q_5 &= 123A^{0.690}S^{0.383} \\Q_{10} &= 170A^{0.680}S^{0.373} \\Q_{25} &= 243A^{0.668}S^{0.366} \\Q_{50} &= 305A^{0.660}S^{0.356} \\Q_{100} &= 376A^{0.652}S^{0.346} \\Q_{500} &= 596A^{0.636}S^{0.321}\end{aligned}$$

where,

Q_t =estimated discharge in cubic feet per second (cfs)

A=drainage area in square miles

S=main channel slope in feet per mile

Discharges in excess of 9,000 cfs occur every five years in the North Fork, Middle Fork, Elk Fork, and South Fork (Table 4). Prior to the construction of Clarence Cannon Dam, discharges in the lower Salt River exceeded 40,000 cfs every two years.

Dam and Hydropower Influences

Actual construction of Mark Twain Lake and Clarence Cannon Dam began in 1970 and was completed in 1983. The dam impounds the upper Salt River about 63 miles upstream from its confluence with the Mississippi River. Approximately 165 miles of the river and its tributaries were inundated. The dam has two hydropower units capable of producing 58,000 kilowatts of electricity. One of the units is designed to become a pump when operated in reverse. It can be used to return water to the lake during extremely low lake level periods to be reused for power generation. A second dam (re-regulation dam) about 9.5 miles downstream of the main dam impounds water for the pump back generation. This pump back feature was tested twice in 1984 and has not been used since. At normal pool of 606 M.S.L., the lake has a surface area of 18,600 acres and storage of 457,000 acre-feet. The top of the tainter gates is 638 M.S.L., at which time the lake would cover 38,400 acres and have 1.43 million acre-feet of storage.

Low dissolved oxygen concentrations in the re-regulation pool caused by hypolimnetic lake water moving through the turbines is a major water quality concern. A temperature control weir was constructed about 400 feet in front of the main dam to act as a skimming weir so the turbines would draw a mixture of epilimnetic and hypolimnetic water during periods of lake stratification. However, when the lake level is high (625 M.S.L.), the metalimnion may stabilize as much as 19 feet above the crest of the weir (580 M.S.L.) allowing poorly oxygenated, hypolimnetic water to pass through the turbines and into the re-regulation pool during generation. During periods of non-generation at this elevation, hypolimnetic water fills the forebay between the weir and main dam. This water leaks through the wicket gates into the tailwater. Upon start up of generation, this poor-quality water is flushed downstream. Current operational procedures during periods when the turbines cannot discharge water with adequate dissolved oxygen concentration calls for

opening the tainter gates so that one-third of the discharge is from the tainter gates (surface release from the lake) and two-thirds is through the turbines. Discharge exclusively through the tainter gates will be used when oxygen concentrations in the re-regulation pool remains too low.

Low discharge and poorly oxygenated water moving through the re-regulation dam into the lower Salt River is also a concern. A surface water intake was recently constructed at the re-regulation dam so that oxygenated surface water would pass through the dam instead of bottom water with little dissolved oxygen. A minimum of 50 cfs is released through the dam to maintain downstream flows and adequate water quality. Maximum discharge through the re-regulation dam is 6,000 cfs from April to November (growing season), but during the winter months it may be as much as 12,000 cfs (D. Foss, U.S. Army Corps of Engineers, personal communication). Discharges are significantly reduced, no more than 2,500 cfs, when the Mississippi River is at flood stage.

I used the Indicators of Hydrologic Alteration (IHA) and Range of Variability Approach (RVA) to closely examine how Clarence Cannon Dam has altered streamflows in the lower Salt River (Richter et al. 1996, Richter et al. 1997). This method assumes that natural variation in hydrologic regimes is necessary to sustain native biodiversity and function of aquatic ecosystems. The IHA uses daily discharges to compute measures of central tendency (mean or median) and dispersion (standard deviation or percentiles) for each of 33 hydrologic parameters for each year in a data series, i.e., one set for the pre-dam period and one for the post-dam period (Table 5). The RVA uses the pre-impact values to establish a natural range of variation for each parameter. Post-impact means or medians can then be compared to the RVA target ranges to determine which parameters have been significantly altered (fall outside the natural range of variation). I chose parametric procedures to describe each parameter for the Salt River at New London. Because construction of Clarence Cannon Dam began in November 1970, the pre-impact period was set as 1923 - 1970. The post-impact period was defined as 1983 - 1996. RVA target ranges were computed from the pre-dam means + or - one standard deviation unless targets fell outside of the pre-dam data range. When this occurred, the 25th or 75th percentile was used to set the lower or upper limit, whichever fell outside of the data range.

Based on 48 years of pre-dam and 14 years of post-dam data, mean annual flow was higher during the post-dam period (2,077 cfs compared to 1626 cfs), indicating more precipitation and/or run-off during the last 14 years. However, the coefficient of variation was lower from the post-dam period (1.5) than from the pre-dam period (2.6). The means of ten of the 33 flow parameters from the post-dam period were outside the RVA target ranges (Table 5). Post-dam means for 21 of the 33 parameters were outside the RVA target ranges in at least 4 of the post-dam years (>30%), and means of 12 parameters were outside target ranges in at least half of the post-dam years ($\geq 50\%$).

Primarily due to the construction of Mark Twain Lake, Bachant et al. (1982) projected that the recreational value of the Salt River basin would increase from a statewide ranking of 19 to a ranking of 12 (out of 38 basins evaluated).

Table 4. Flood discharges for 5, 25, and 100 year intervals at stream flow gaging stations in the Salt River basin (Alexander and Wilson 1995).

Location	Drainage Area(mi ²)	Gradient	Flood Discharge (cfs) for interval (ft/mile)		
			5	25	100
North Fork Hagers Grove	365	5.2	15,900	25,500	33,300
North Fork Shelbina	481	3.9	10,400	16,800	22,600
Easdale Br. Shelbyville	0.7	59.9	537	842	1,110
Oak Dale Br. Emden	2.6	32.3	1,000	1,620	2,200
Bean Cr. Mexico	3.0	33.1	1,200	2,410	3,750
South Fork Santa Fe	298	3.6	12,500	19,600	25,800
Youngs Cr. Mexico	67	7.5	4,480	7,480	10,000
Middle Fork Paris	356	2.9	9,320	17,400	26,600
Elk Fork Madison	200	4.1	13,700	26,900	41,600
Salt River Monroe City	2,230	2.8	41,900	67,300	92,300
Lick Cr. Perry	104	6.2	8,560	12,500	15,500
Salt River New London	2,480	2.5	40,200	62,300	83,100
Spencer Cr. Frankford	206	5.6	15,000	19,600	22,800

Table 5. Results of Indicators of Hydrologic Alteration analysis for the Salt River at New London, Missouri. Range of Variability Approach (RVA) targets are based on + or - 1 standard deviation of pre-dam means, except when targets fall outside of pre-dam range limits. When this occurred, the 25th (lower target) or 75th (upper target) percentiles were used. Streamflows in cubic feet per second. * indicate post-dam means falling outside of RVA targets.

Parameter	Pre-Impact Mean	Post-Impact Mean	RVA Targets	Percent of Years Outside of RVA Targets
Monthly Flow				
October	1020	1415	29-2934	14
November	930	1861	42-2377	29
December*	755	2726	49-1828	36
January	1141	1380	65-2495	29
February	1812	1467	177-3447	7
March	2393	2910	439-4348	36
April	2947	2798	680-6035	36
May	2328	2734	382-5135	29
June	2529	2821	546-5214	36
July	1500	2218	189-4055	43
August	895	1333	166-2501	21
September	1053	1220	84-3284	14
Min/Max Flows				
1-day minimum*	17	38	0-34	50
3-day minimum*	18	41	0.5-36	64
7-day minimum*	20	49	0.8-39	64
30-day minimum*	46	139	7-102	43
90-day minimum	165	375	27-381	29
1-day maximum*	28167	11879	14437-41897	71
3-day maximum*	24110	11307	11784-36436	50
7-day maximum	16029	10686	7554-24505	29
30-day maximum	7139	7885	317-24505	
90-day	3918	5043	1819-6017	36

Table 5 continued

maximum				
# of zero days	0.5	0	0-3	0
Base flow	0	0	0-0	43
Day of year minimum flow	263	278	239-287	64
maximum flow*	140	176	109-170	86
Low pulse count	6	8	3-9	64
Low pulse duration	11	6	5-18	79
High pulse count	7	6	4-11	43
High pulse duration*	3	6	2-4	71
low pulse threshold is 65 (25th percentile)				
high pulse threshold is 5878 (+1 sd)				
Rise rate	1352	759	614-2090	21
fall rate	-596	-565	-934- -257	7
# of reversals*	84	155	72-96	93